Potential Solutions for Managing Real-Time ECG/Arrhythmia Monitoring Alarms: A Review

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Abstract

Electrocardiographic monitoring, which allows for continuous non-invasive detection and documentation of cardiac arrhythmia, is one of the most frequently used monitoring procedures for managing in-hospital patients. The most often cited issue of using these systems is the large number of alarms generated by these systems. These alarms include both false alarms and repetitive non-actionable true alarms. This paper provides an overview of potential solutions for managing these alarms.

Device based solutions for false alarm reduction include a) providing more specific information in assisting users to identify the root cause of the false alarms, and b) continuing the development of more robust ECG and multi-parameter based algorithms.

Frequent repetitive non-actionable alarms can be reduced and managed by developing a more robust alarm generation structure. An overview of the key features/components of a robust alarm generation structure is provided with an example to show how such a system could be used to manage and reduce the repetitive non-actionable alarms.

Despite continuous development of the computerized ECG/arrhythmia monitoring systems over the last several decades, numerous opportunities still exist to further improve the usability of these systems. In addition to continuous algorithm enhancement (both ECG and multi-parameter based), other potential areas for enhancement include: better user support tools for trouble-shooting and work around, and better and more flexible alarm generation structures.

1. Introduction

Electrocardiographic monitoring, which allows for continuous non-invasive detection and documentation of cardiac arrhythmia, is one of the most frequently used monitoring procedures for managing in-hospital patients [1]. Current commercial systems are designed to detect most of the ventricular arrhythmias and some of the atrial arrhythmias for patients of all age groups.

The most often cited issue of using these systems is the large number of alarms generated by these systems [2]. The alarms include both false alarms and repetitive non-actionable true alarms. Due to the large number of QRS complexes that are analysed (~100,000 complexes per patient per day at an averaged heart rate of 70), even a fairly accurate algorithm will generate a large number of false positives/alarms. Many studies have been reported to reduce the number of alarms using various methods [3 - 5]. To reduce the large number of alarms, both true and false alarms need to be addressed. This paper provides an overview of all the potential solutions for effective managing of these alarms.

2. Methods of alarm reduction

The methods of alarms reduction for both true and false alarms are summarized in Fig. 1. For each alarm type both users' action and device-based solutions are listed.

2.1. False alarm reduction

Device based solutions for false alarm reduction include a) providing more specific information in assisting users to identify the root cause of the false alarms and providing simply work around to allow for continuous monitoring, and b) continuing the development of more robust algorithms.

Examples of useful information that could be provided by the device in supporting root cause identification and easy work around tools are described.

In addition to the enhancement of existing ECG based algorithms, the development should also include multi-parameter algorithms that incorporate simultaneous analysis of both ECG and non-ECG signals, such as blood pressure and pleth. Most methods currently used for multi-parameter analysis are based on post alarm trigger, which is not very desirable. Because of the time delay, it may not be practical to correct the erroneous real-time output information already provided to the monitoring system. This could cause inconsistent data and information being stored in the system.

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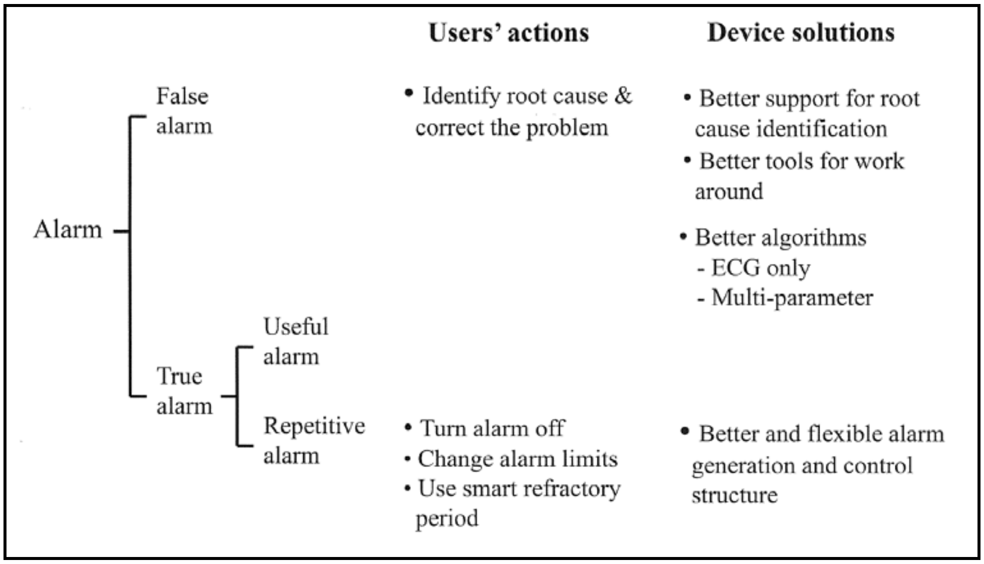

Figure 1. Summary of solutions for managing ECG/arrhythmia monitoring alarms

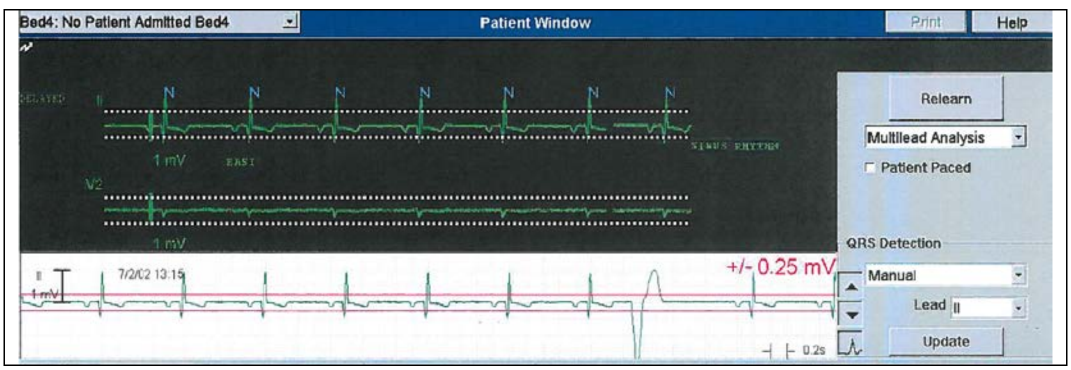

Figure 2. Examples of simple trouble-shooting support tools: beat annotation and beat detection

2.1.1. Tools for trouble shooting

An example of the tools for trouble shooting is shown in Fig. 2. In the picture, beat labels generated by the algorithm are displayed together with the ECG signals. The beat labels allow the users to understand quickly why certain alarms are generated. Too many artifact beat labels easily suggest to the users that a lead change may be required. The graphical QRS detection threshold indicated by the horizontal lines on the ECGs allows the users to see why some beats are not detected and thus be able to determine the root cause of a pause or asystole alarm. The problem can then be corrected by selecting leads above the threshold or by using the user adjustable threshold to allow for more accurate QRS detection.

2.1.2. Better algorithms

Although commercial systems developed over the last several decades have improved significantly in terms of PVC detection performance tested on the publically available databases [6,7], the number of false alarms generated from these systems under certain circumstances are still too high. Further improvement remains necessary to reduce the level of false alarms.

2.1.2.1. ECG based algorithm

Future development should consider the following: 1) Develop the ability to process all available leads. Current algorithms only process a limited number of leads.

Additional datasets with full set of leads are needed. Performance results reporting also need to be enhanced [8,9]. 2) Develop the ability to perform atrial analysis. 3) Develop improved paced algorithm. Need to add the ability to detect pacemaker undersensing. Publically available paced datasets are needed. Pace pulse test specifications need to be enhanced to include both biventricular and multi point pacing [9,10]. 4) Develop improved pediatric and neonate algorithm. Publically available datasets are also needed for these age groups.

2.1.2.2. Multi-parameter based algorithm

Despite numerous developments in this area there is very limited application for commercial systems. Recent PhysioNet/Computing in Cardiology challenge 2015 titled "reducing false arrhythmia alarms in the ICU" drew a total of 38 entries [10]. The five life-threatening arrhythmia events included for suppression were: Asystole, VF, VT, Extreme Tachy, and Extreme Brady. The ranking was based on the following scoring function:

$$\text{Score} = \frac{100 \times (TP + TN)}{TP + TN + FP + 5 \times FN}$$

Although there is a heavy penalty for suppression of true alarms, for clinical application it is critical that no true alarms are suppressed at all regardless of the gain on false alarm reduction. The rates of unsuppressed true alarms for the top ranked nine entries are summarized in Table 1. These results show that all algorithms had difficulty to ensure that no true alarms were suppressed.

2.2. Non-actionable true alarm reduction

2.2.1. Arrhythmia alarm structure

Due to the large number of arrhythmia alarm conditions that are monitored, to reduce the number of alarms generated, a robust alarm structure needs to be developed. The goal is to reduce the generation of redundant and lower priority alarms while making sure that all higher priority alarms are not suppressed. To accomplish this, an example of an arrhythmia alarm structure is shown in Fig 3.

The alarms are arranged in descending priority order. A higher priority alarm will override a pending lower priority alarm and a lower priority alarm will not replace a pending higher priority alarm. For alarms with the same priority, the most current alarm detected will have higher priority. Furthermore, similar alarms are grouped together and within each group the higher priority alarms will override the lower priority alarms. Alarms from another group will have the same priority to ensure that a different type of arrhythmia alarm will be annunciated to the users.

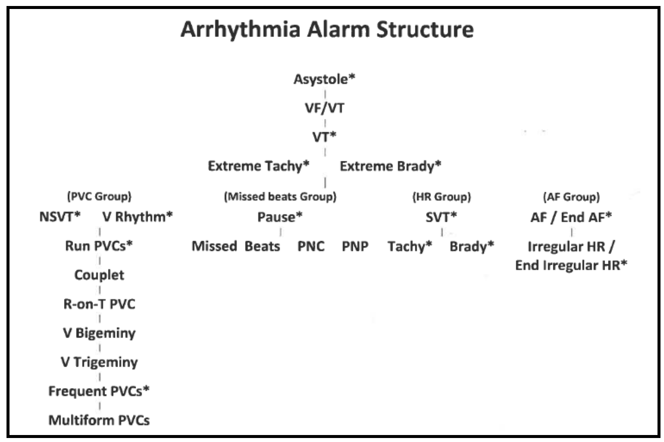

Figure 3. An example of arrhythmia alarm structure

2.2.2. Enhanced refractory period

Current alarm systems generate an alarm when either an alarm limit is violated or an alarm condition is detected. One issue with this type of alarm structure is

Table 1. Summary performance of the percentage of unsuppressed true alarms achieved by the top nine ranked algorithms.

Rank	1st Author	Asystole (*n*=12)	VF (*n*=6)	VT (*n*=45)	Extreme Tachy (*n*=68)	Extreme Brady (*n*=26)
1	Plesinger	**100%**	67%	85%	97%	**100%**
2	Kalidas	78%	**100%**	90%	**100%**	87%
3	Krasteva	82%	78%	85%	98%	**100%**
4	Couto	78%	89%	69%	**100%**	95%
5	Fallet	83%	89%	94%	97%	**100%**
6	Antink	56%	67%	90%	**100%**	**100%**
7	Eerikainen	89%	22%	81%	98%	**100%**
8	Ansari	94%	**100%**	78%	98%	77%
9	Liu	89%	89%	79%	98%	90%

the problem that too many alarms are generated when alarm conditions persist. As an example, the alarm behavior of AF is shown in Fig. 4. The black horizontal lines indicated the presence of AF. The black arrows indicated where the AF alarms occurred. The gray areas were the fixed alarm refractory period. When a patient is in chronic AF condition, at a rate of six per hour a total of 144 alarms will be generated in 24 hours assuming the alarm system has a 10-minute time-out after each alarm is detected. Thus for these patients many care units will turn the AF alarm off to reduce the large number of non-actionable alarms.

To overcome this problem, a modified alarm refractory period is shown in Fig. 5. The enhanced system automatically extend the refractory period when AF conditions persist. The maximum extension time can be controlled by the users. In addition to alarm on the on-set, the modification also triggers an alarm when the AF ended. To prevent too frequent AF and AF-end alarms during intermittent AF, a user adjustable end delay time is provided,

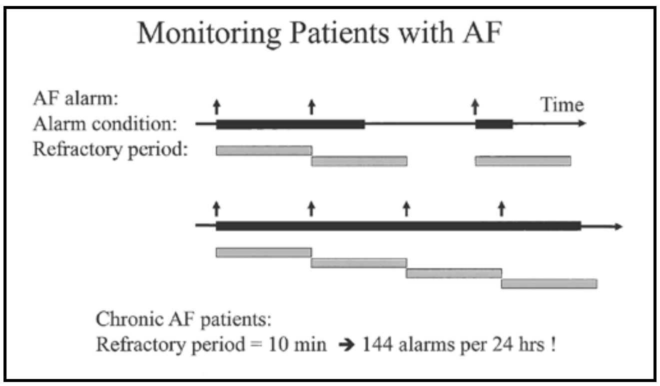

Figure 4. AF monitoring alarms

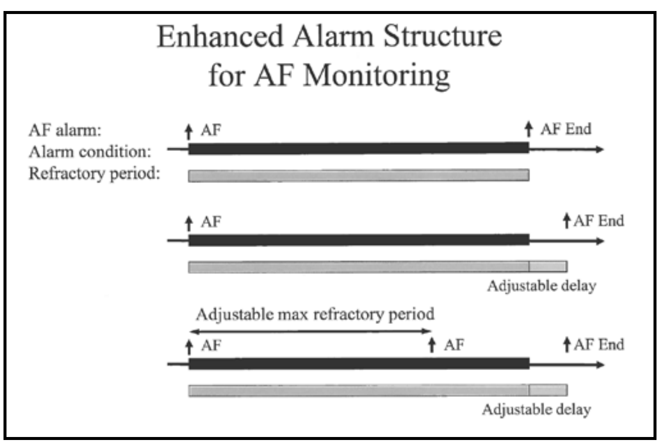

Figure 5. Enhanced AF monitoring alarms

3. Conclusion

Computerized Electrocardiographic monitoring was introduced for clinical use in the 70s. Based on continuous users' feedback and advancement in computing technologies, commercial systems have improved significantly over the years. As before, it is expected that the identified issues will be the main focus of future development for commercial systems. As discussed, the improvement will come from better user support tools for trouble-shooting, more accurate analysis algorithms including both ECG and multi-parameter based, and better alarm generation structures.

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